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Mod 1 ICS TI Report

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LLNL 15-S-059: LANL Deliverable: Evaluate "Mod 1"

ICS Conversion of a 140% HPGe Detector

This report evaluates the Mod 1 ICS, an electrically cooled 140% HPGe detector. It is a custom version of the ORTEC Integrated Cooling System (ICS) modified to make it more practical for us to use in the field. Performance and operating characteristics of the Mod 1 ICS are documented, noting both pros and cons. The Mod 1 ICS is deemed a success. Recommendations for a Mod 2 ICS, a true field prototype, are provided.

Background

We have a number of 140% relative efficiency HPGe gamma detectors. They are mounted on 3-liter liquid nitrogen (LN2) dewars and need to be kept cold. The 3-liter dewars last a nominal 24 hours before refilling is necessary. Unfortunately, LN2 is both cumbersome to transport and inconvenient to nearly impossible to obtain promptly in the field.

The portable electronics we use with these HPGe's are called Gamma Boxes. They consist of a Windows XP laptop, an ORTEC digiDART, and associated cabling. As the XP software should indicate, they are past due for replacement.

Nearly two years ago, we undertook looking at options for upgrading our Gamma Boxes and then expanded it to looking at options for getting away from LN2-cooled detectors. The five options we considered are summarized in Table 1. Our first and most simple option was to replace only the Gamma Boxes, but that would still leave us with the LN2 problems. Option 2 was to alleviate our LN2-in-the-field problem by deploying with an LN2 generator (large, heavy and a single point of failure) or using an electrically cooled HPGe with a built-in LN2 reservoir (the ORTEC Mobius™ or similar, which are not designed for use in the versatile geometries that our current HPGe dewars can handle). This second option was deemed unpalatable.

The other three options we considered would each allow us to completely drop LN2. The ORTEC Detective is a well-known electrically cooled 10% or 40% efficiency HPGe. We have been after ORTEC to build a "140% Detective" for many years. The high efficiency coolers necessary to support a 140% HPGe have only become available in the last two years and so far have only been implemented in ORTEC's benchtop, AC-powered ICS.

Option	Pros	Cons
Keep current LN2 system	Familiarity ~no cost	LN2 can be hard to come by Gamma boxes need updates
Mixed LN2/electric system (LN2 generator or cooler with LN2 reservoir)	Best of both worlds Minimal LN2 usage, no electricity needed on plane Can use existing PopTops	Worst of both worlds? Gamma boxes need updates Collimator support needed Not all-angle use Need smaller system than COTS
Existing ORTEC ICS cooler	Available now No short cycling	Gamma boxes need updates BNC connections fragile Will look kludged Collimator support needed Needs 100W each on plane
LANL-modified ICS cooler	Can build-in Gamma box Can build-in collimator support No short cycling	Lab-Expensive to develop Starts warming up immediately ORTEC can build smaller package
ORTEC-modified ICS cooler	Can make Detective-like Can build-in collimator support No short cycling	Expensive to develop Starts warming up immediately

Table 1. Considerations in going with a modified ORTEC ICS

Referring still to Table 1, the third option and the first LN2-free option, would be to use the ORTEC ICS as is, a COTS system. Unfortunately it is intended for a laboratory environment and has several drawbacks in its design compared to the field instrument we would want to use. Option 4 is that as a national laboratory, we could purchase and then modify an ICS ourselves, but we realized that this would be a lengthy and expensive effort. In consultation with ORTEC, they expressed a willingness to make changes to their ICS for us, which is Option 5.

The Gamma SPI visited ORTEC in October of 2014 to see an actual ICS. During the visit, he determined that the ICS had several positive features:

A. it was a reasonable size,
B. it was very quiet
C. the power requirements were not prohibitive
D. the expected cooler lifetime was excellent (200,000 hours, i.e., >22 years)
E. the energy resolution was the same as for an LN2 cooled HPGe.

In addition, the SPI noted several modifications that would make the ICS better for our purposes. Fig. 1 and Fig. 2 are each views of a stock ICS and what we call the Mod 1 ICS. Those changes between the two were

1. eliminated the BNC, SHV and preamp connections in favor of a detector interface module, which is a single-cable connection to a digiDART. We made this change years ago in our field equipment for reliability and ease-of-use concerns.
2. made the detector interface module a SMART version to let us read the detector temperature. This eliminates the need for our present add-on temperature indicator.
3. moved the connections from their current location, which is the side we would most often want to use as the bottom, to the side opposite the detector
4. eliminated the narrow neck extension to the detector, making the detector more wieldy and improving heat conduction from our larger HPGe crystal
5. used a nose capsule that will fit inside our existing collimators

Although battery-powered operation would be a requirement for the field, we chose not to have ORTEC develop that.

Fig. 1 The commercial Integrated Cooling System (ICS) offered by ORTEC (top) and the Mod 1 ICS (bottom). Relative to the off-the-shelf ICS, the entire unit is rotated and the nose is shorter.

The actual Statement of Work with ORTEC is given in Attachment 1. Note they refer to Mod 1 as Phase 1. We choose to call it the Mod 1 so people do not falsely associate it with deployment phases.

The ORTEC quote for the Mod 1 was for $67k. It did not include the cost of an HPGe crystal. The standard ICS itself, with no HPGe, costs $35k. Most of the rest of the costs were one-time engineering and testing charges, or what they refer to as Non Recurring Engineering (NRE) costs. Livermore National Laboratory paid for this quote in FY2015 using money from their LLNL 15-S-059 TI project that they have to design and build their own HPGe electric cooler.

The Statement of Work with ORTEC also speaks of a Phase 2. None of the Mod 2 has been funded to date since it relies on the success or failure of Mod 1 testing. It was included in the SOW to make sure everyone had the same mindset of what should be happening and when.

Since a new 140% HPGe crystal costs over $100k and takes considerable length of time to be manufactured, it was decided that we would convert our HPGe Detector R into the Mod 1 ICS. Detector R was one of our better 140% detectors, with good reliability and minimal neutron damage. It was chosen to provide a fair test of the Mod 1 ICS.

The Mod 1 required shipment of detector R from LANL to the factory in Oak Ridge, TN for teardown, engineering, modification, manufacture and testing. While awaiting the Mod 1 construction, LANL drew up a preliminary design for a collimator support for the ICS that would mate it with our existing collimators. The drawings were done by hand to minimize costs in FY15 since LANL itself did not yet have ICS-specific funding. In FY15, and in addition to paying for the Mod 1 quotation, LLNL built the collimator support parts under their TI code and sent them to LANL. The collimator support and one of our existing collimators is shown in Fig. 3.

Once ORTEC finished the Mod 1, it was sent to LLNL who did some of their own testing of the ICS. After passing through Albuquerque and elsewhere it finally made it to LANL for the tests described herein. LLNL has not been involved with the Mod 1 ICS in FY16.

The LANL tests pertinent to a Mod n ICS being palletized someday are described in the next section of this report, following Figure 3.

Fig. 2. The electrical connections on a stock ICS (left) and the Mod 1 ICS (right). The 4 BNC's, 1 SHV and the 9-pin preamp connector were replaced with a single Smart Interface Module connector, and the power receptacle, LED's and on/off switch were moved to the side opposite the detector.

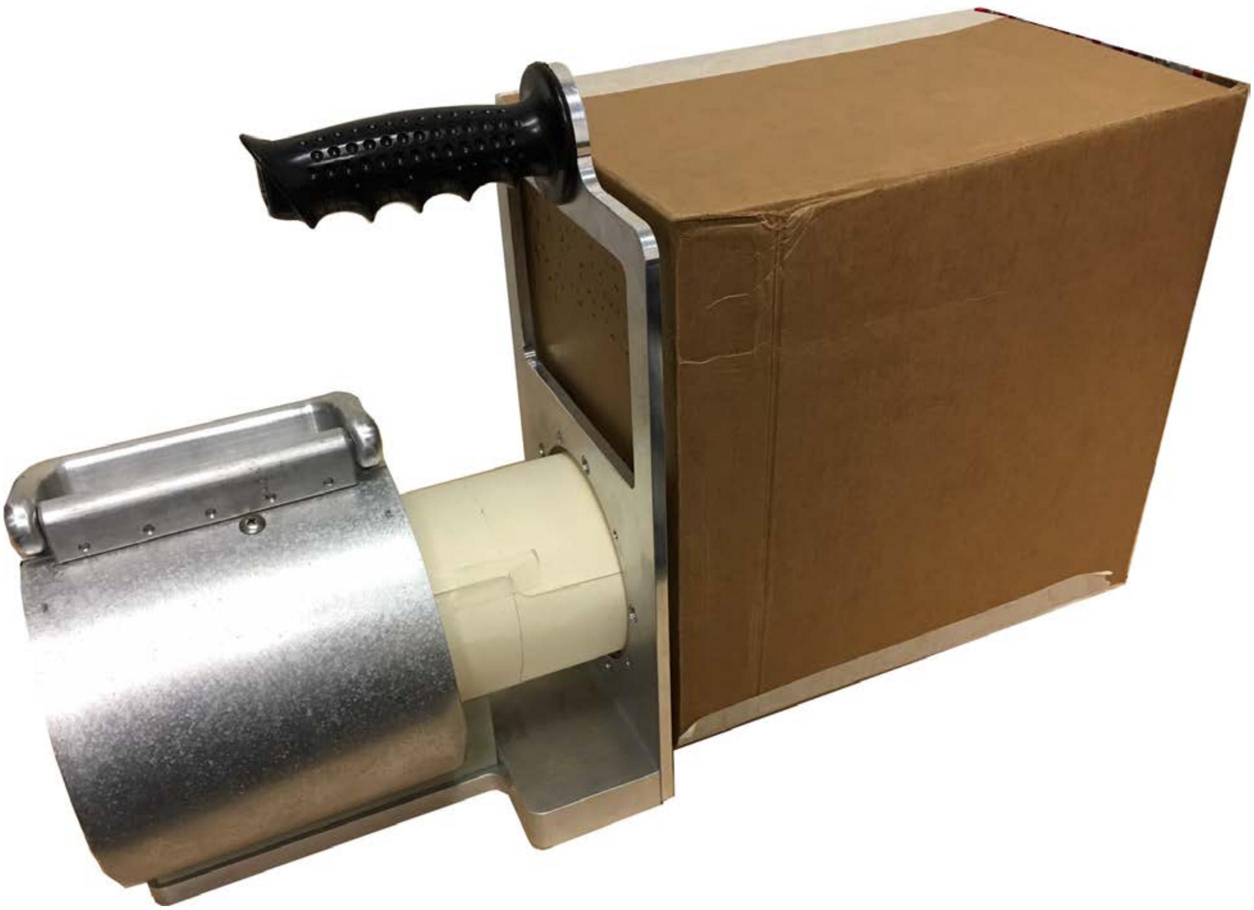

Fig. 3. The collimator and collimator support built for the Mod 1 ICS. It is shown attached to the cardboard surrogate we made as a design aid in FY15 while awaiting delivery of the Mod 1 ICS.

Mod 1 ICS Evaluation (TI work completed in FY16):

Since determining the electrical cooling abilities and its effects were the priority of the Mod 1 ICS, no attempt was made to have ORTEC make modifications other than those five items listed on page 3. In particular, their ICS is AC powered and needs external electronics similar to our Gamma Box to acquire data. For these LANL tests, we used a laptop computer and a standalone digiDART to obtain data from the ICS. Ideally, the data acquisition electronics would be built into a fieldable ICS.

When finally received at LANL, the Mod 1 ICS would not allow the high voltage to be applied to let us to take data. ORTEC fully cooperated with troubleshooting what turned out to be a firmware problem in the interface module, and they supplied us the undocumented command to easily fix the problem should it ever recur (it has not). That command is SET_SHUTDOWN_SMART using the Diag.exe program that comes with the Maestro software.

ORTEC was also generous in giving us their LabVIEW virtual instrument software, or .vi, to talk to the digiDART. We were able to modify it and use it to let the computer record the detector temperature as a function of time.

There is far more that we could do with this .vi software. For example, the existing Gamma Box software is written in Microsoft Visual Basic 6, which is no longer supported. National Instruments LabVIEW software has been around for more than twenty years and has continuous support. Our Gamma Box data acquisition programs could be rewritten in LabVIEW. The ORTEC .vi's could also be used for state of health monitoring and notifications of alarms via email while the detectors are staged. Such LabVIEW programming is beyond the scope of this TI, but we note it here as a reminder for future consideration.

Among the tests LANL conducted was the tracking of the temperature to document cool-down and warm up times, both from room temperature down and from various power-off times when cold. Fig. 4 shows the time for the Mod 1 ICS to cool down from room temperature to operating temperature, compared to a few LN2-cooled 140% HPGe's and a Detective EX. The Mod 1 ICS cools down as quickly or more so than any of the other detectors measured thus far. This was a pleasant surprise. Operating temperature for the Mod 1 ICS, the temperature at which one can apply high voltage, was measured to be 123° K or less. The steady state cold temperature was measured to be about 100°K.

Fig. 4 also shows the time it takes for the Mod 1 ICS to warm up back up to room temperature compared to these several detectors. The Mod 1 ICS starts warming immediately when power is removed, but it takes longer to reach room temperature. This indicates superior insulation in the Mod 1 ICS compared to an empty LN2-cooled HPGe.

From the steady state cold temperature, we chose various times for the power to be off, bracketing anticipated transition times in the field. As is the case with LN2-cooled detectors, the ICS is interlocked to prevent applying high voltage when the detector is too warm, to prevent blowing its first-stage electronics. We measured temperatures for power-off durations of 5, 15, 30, 60, 120 and 240 minutes (Fig. 5). The power-off tests show the detector warms immediately and reproducibly. When power is re-applied, it cools back down enough to allow high voltage in about ¼ the time it was off, but it takes about three times as long as it was off to return to its steady state temperature. As with any HPGe, the gain is not constant during the time the temperature is changing. Spectra acquired before the Mod 1 ICS (or any HPGe) is at steady state temperature will have broadened gamma peaks from this gain change. The Mod 1 ICS down times have been judged to be acceptable for our uses. Fig. 6 summarizes the time to allow HV to be re-applied and the time to reach stability versus the length of time the detector is off.

Whereas at first these re-cool down times may seem like a negative, compared to LN2-cooled detectors it is an improvement. Once they are more than about 20 degrees above their operating temperature, we allow LN2-cooled HPGe's to warm up completely before being re-cooled. This prevents contaminants in their imperfect vacuum from plating out on the detector crystal and ruining the detector resolution. The entire warm up/cool-down process for an LN2-cooled HPGe takes more than 24 hours. Not taking this time is referred to as "short-cycling" the detector. Because of its different construction and active cooling, the ICS can be re-cooled immediately like a Detective.

Another success in the Mod 1 ICS testing was use of the collimator support mounted to the Mod 1 ICS. The collimator support worked well and not unexpectedly, will need just a couple of easy tweaks for a Mod 2 ICS. In particular, it will have better positioning of the handle over the center of gravity, and it will have a secure latch for the collimator to allow the unit to be pointed in any orientation. No picture of the Mod 1 ICS with the collimator was available for this report.

As mentioned earlier, the ICS is advertised to have a mean time to cooler failure of over 200,000 hours, or 22 years.

The Mod 1 ICS uses an external power brick that supplies 24 V DC. Since AC power is not a given for field use, we measured the power draw of the Mod 1 ICS: 3 to 3.3 Amps at 24 Volts for initial cool-down, and 2.2 Amps at 24 Volts when cold. Thus the Mod 1 ICS was measured to have a power draw of 52 to 78 W. This does not include the power needed by the external data acquisition electronics.

For unknown reasons, we were explicitly told to not work on a battery supply as part of this TI project. Because of the great importance of knowing how long the Mod 1 ICS could run off of a reasonable size battery pack, we used non-TI monies and built a benchtop battery system from commercial parts (Fig. 7). The battery system used the ORTEC power brick, four 12 V Li ion batteries of the type used in the MC-15, a commercial four-Li-battery charging and monitoring circuit, and a commercially available 12 V to 24 V converter board capable of handling a few amps. It runs off anywhere from one to four batteries, and the batteries are hot swappable. The batteries will charge while the unit is operating on AC. Four new batteries kept the detector cold for 8.1 hours. This length of time is envisioned as long enough for most transport scenarios and for its use on target in the field. When not in transport or being used, the Mod 1 ICS should be AC powered. We foresee this same battery system being built into any Mod 2 ICS.

Cooling from room temperature takes 10 to 12 hours and requires more current than steady state operation. It would drain all four batteries before steady state was reached, so that would be done under AC power in all but extreme circumstances.

The QA data sheets for the Mod 1 ICS and for our detector R from which the HPGe crystal came were compared. The crystal dimensions are unchanged. Originally detector R had a resolution of 1.94 keV for Co-60 at 1332 keV and a peak-to-Compton ratio of 99. The Mod 1 ICS has a resolution of 2.4 keV and a peak-to-Compton of 78. Both poorer resolution and a lower peak-to-Compton can be expected from 11 years of use, especially in the presence of neutrons. Our cutoff criterion for our 140% detectors is that the even higher energy and hence broader K-40 resolution (peak at 1460 keV) be less than 3.2 keV in background spectra. Detector R was measured quarterly and has always met that criterion. The Mod 1 ICS also passes this criterion.

The ICS is advertised to have a resolution comparable to LN2-cooled detectors. Although the Mod 1 ICS had good resolution at low count rates, we found that, as received, it did not have good resolution at the highest count rates we use (Table 2). We systematically measured both the Mod 1 ICS and an LN2-cooled 140% HPGe at count rates of 5, 10, 20, 40 and 50 kcps. The Mod 1 ICS was measured at both the 12 microsecond rise time ORTEC used for their data sheet, and at the 6 microsecond rise time we use. We then used our LN2-cooled detector S with our usual 6 microsecond rise time as a reference for what we expect (all of our detectors labeled H and higher are 140%ers).

Both detector S and the Mod 1 ICS at 6 microseconds showed 25% broadening of the peaks at the higher count rate. However, at 6 microseconds the Mod 1 ICS peaks were wider to start with and fell out of our acceptance range at the higher rates. At 12 microseconds, the Mod 1 ICS resolution was better than detector S at low count rates, but it couldn't handle the high count rates, hitting 88% dead time and very poor resolution at 50 kcps.

	Count Rate	Resolution (keV)	Dead Time
Mod 1 ICS @ 12us as received	5 kcps	2.75	18%
	50 kcps	5.02	88%
Mod 1 ICS @ 6us as received	5 kcps	3.37	10%
	50 kcps	4.39	66%
Detector S @ 6 us	5 kcps	2.88	10%
	50 kcps	3.63	65%
Mod 1 ICS @ 6 us after repair	55 kcps	3.62	67%

Table 2. Comparison of Energy Resolutions of the Mod 1 ICS and an LN2-cooled 140% HPGe before and after repair. Green/red is pass/fail.

When told of the resolution concerns, ORTEC was eager to troubleshoot the problem. We sent the Mod 1 ICS back to them, and on April 14, 2016 we were told they had found and fixed the problem. They added EMI shielding around the fan inside the Mod 1 ICS to reduce the electrical noise. The gamma ray spectrum they sent to us showed a clear improvement in the data: as the last row in the Table 2 shows, the Mod 1 ICS response is now completely comparable to our LN2-cooled detector S.

Conclusions from the Mod 1 ICS Testing

The Mod 1 ICS has been tested and been shown to meet our resolution and count rate requirements. It has been determined that the power required to operate it is not unreasonable. The cooling characteristics are an improvement over our LN2 cooled HPGe detectors.

We deem the Mod 1 ICS a success and recommend proceeding with a Mod 2 ICS, a field prototype.

Recommendations for a Mod 2 ICS (Proposed FY17 TI work):

The Mod 2 ICS would be a repackaging and improvement of the Mod 1 ICS detector. The goal is to have the Mod 2 ICS be a field prototype that is a drop-in replacement for the current LN2-cooled HPGe's and Gamma Boxes. The weight and cubes of the Mod 2 ICS are similar to the LN2-cooled HPGe and Gamma Box, but the hundreds of pounds and many cubic feet of the LN2 pressurized dewars and LN2 support equipment would be eliminated. The Mod 2 ICS would save the cost, hassles and hazards of liquid nitrogen. Down time due to a warming detector would be reduced because short-cycling will not be a problem. Setup time would be reduced and operation simplified by not having a Gamma Box that needs to be connected and disconnected each time.

The Mod 2 ICS work would include the following:

1. Building-in hot-swappable batteries and charging circuitry of LANL's design to assure compatibility with our other batteries
2. Modifying the Mod 1 ICS collimator support to be integral to the Mod 2 ICS
3. Building-in electronics of ORTEC's design eliminating the need of external electronics to take data. The user interface will be similar to the current Gamma Boxes but may incorporate Peak Easy and MC-15 like features. The actual interface would be decided in close consultation with the Gamma SPI.

4. Addressing other form/function upgrades as identified
5. Making a pallet-worthy shipping container of LANL's design
6. Obtaining commercially available spare batteries and charger manifold for extended operations in a LANL-designed pallet-worthy container
7. Repeating the testing done for the Mod 1 ICS to ensure the Mod 2 ICS still meets our requirements
8. Deploying the Mod 2 ICS on one or more actual exercises and/or existing DAF measurements
9. Documenting the work and results of the Mod 2 ICS testing
10. Writing pallet process application and training documentation

Items 1 thru 5 would be done by ORTEC in close collaboration with the Gamma SPI regarding requirements. This will take the lion's share of the budget for this project. We have been in contact with ORTEC and they are onboard with doing a Mod 2 ICS. ORTEC will need to develop an official quote and have a Purchase Order in place before they begin. Their cooperation has been superb thus far and it is anticipated that the proposed work can be accomplished on time and within the requested budget.

Upon success of the Mod 2 ICS, we would plan to complete the pallet process paperwork to officially add the Mod 2 ICS to the pallet. We would develop training for all users of the instrument. We would define Quarterly Maintenance requirements for the equipment technicians. Conversion of the rest of our 140% HPGe's would happen starting in FY18 or later, depending on funding from yet-to-be-identified sources. We anticipate converting two HPGe's at a time to assure enough of the rest are available for use at any given time.

HPGe detectors are inherently more delicate than most other fielded equipment so environmental, shake and drop tests are not included in our testing. It is anticipated that the above-mentioned shipping container will sufficiently protect the unit from most environments.

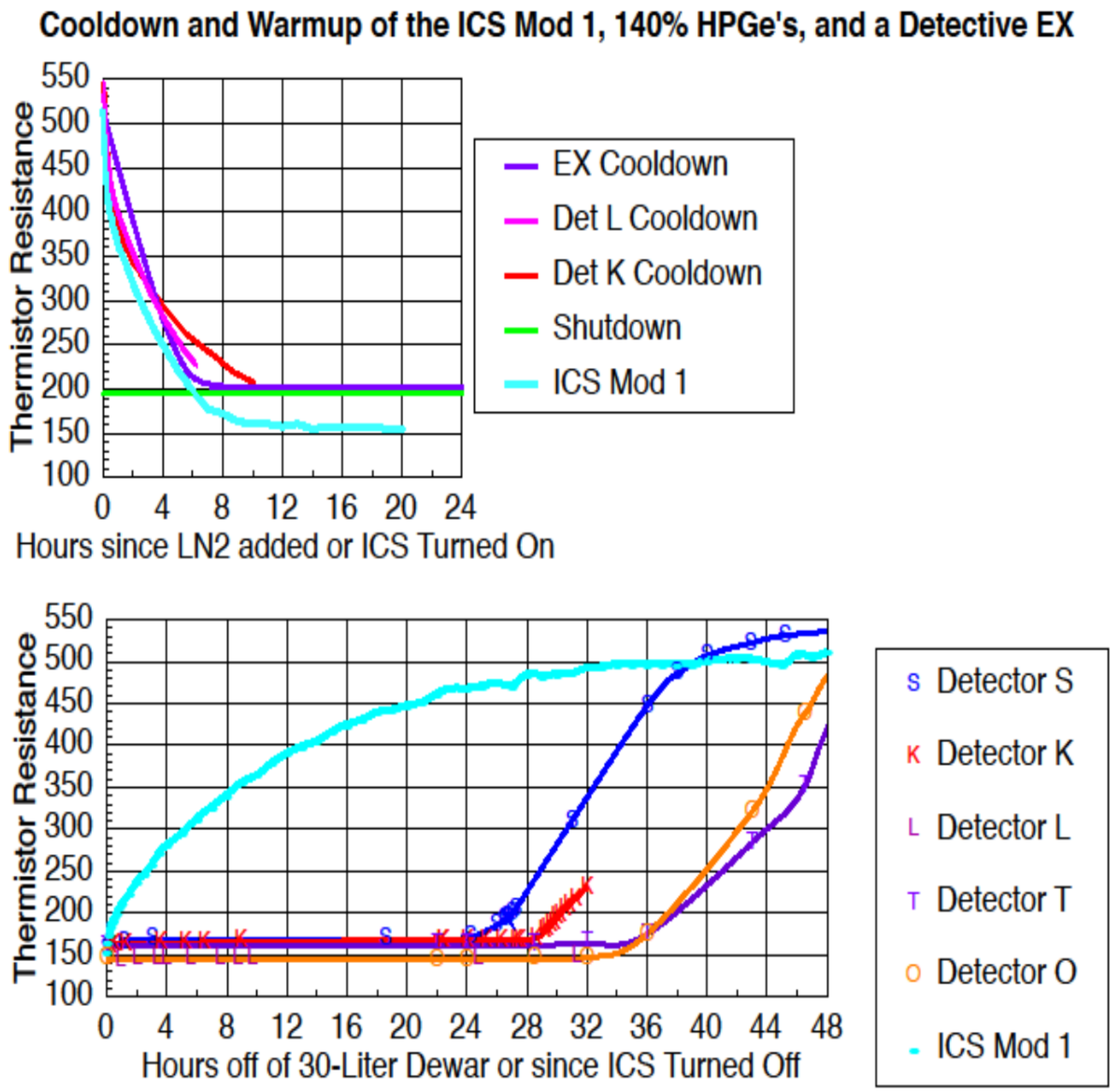

Fig. 4. Time required for various 140% HPGe's to cool down and to warm up. 195 ohms is cool enough to use, 540 ohms is room temperature. The Mod 1 ICS cools faster than the LN2-cooled HPGe's. It starts warming up as soon as power is removed, but takes longer to warm up completely.

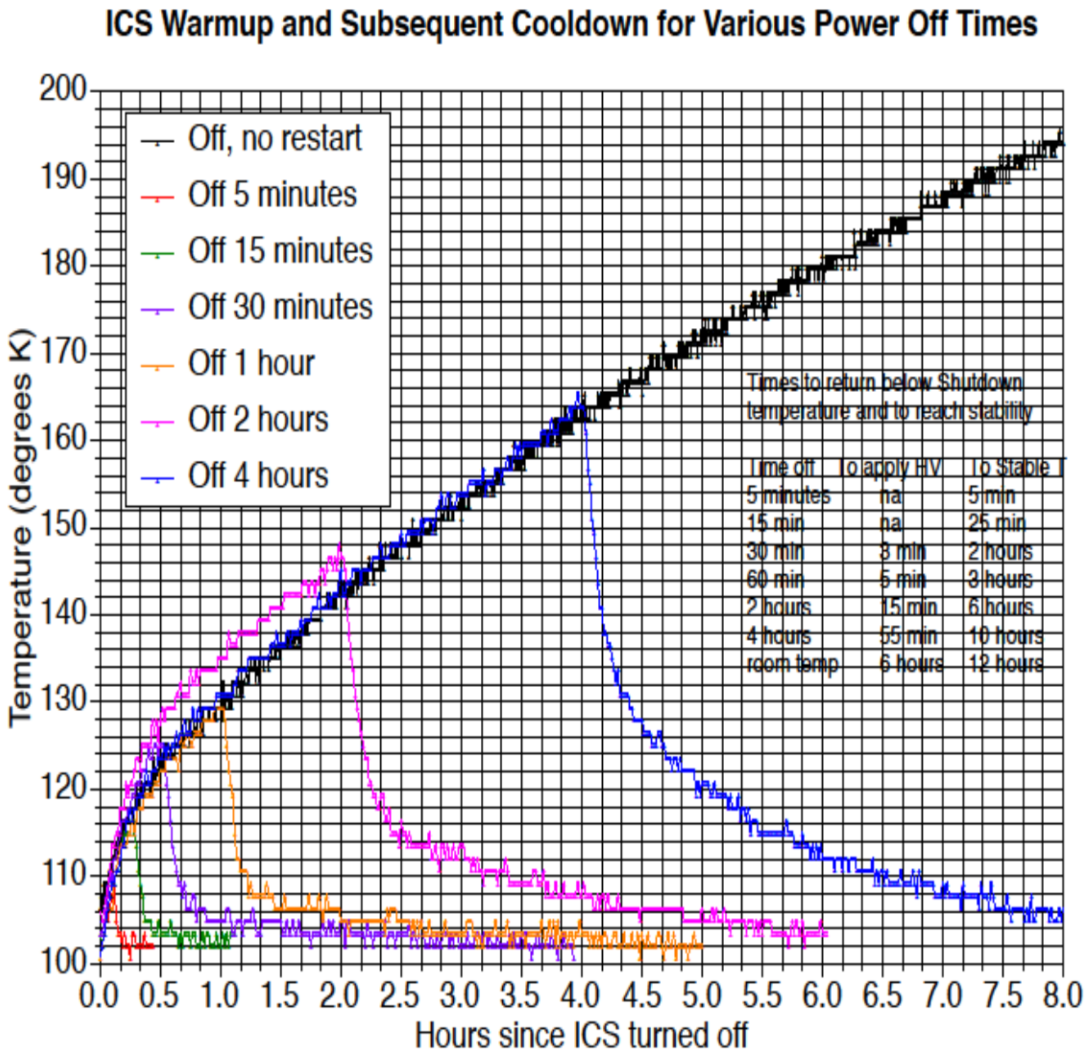

Fig. 5. Mod 1 ICS warm up and subsequent cool down for various power off times. Unlike an LN2-cooled HPGe, the Mod 1 ICS can be re-cooled immediately.

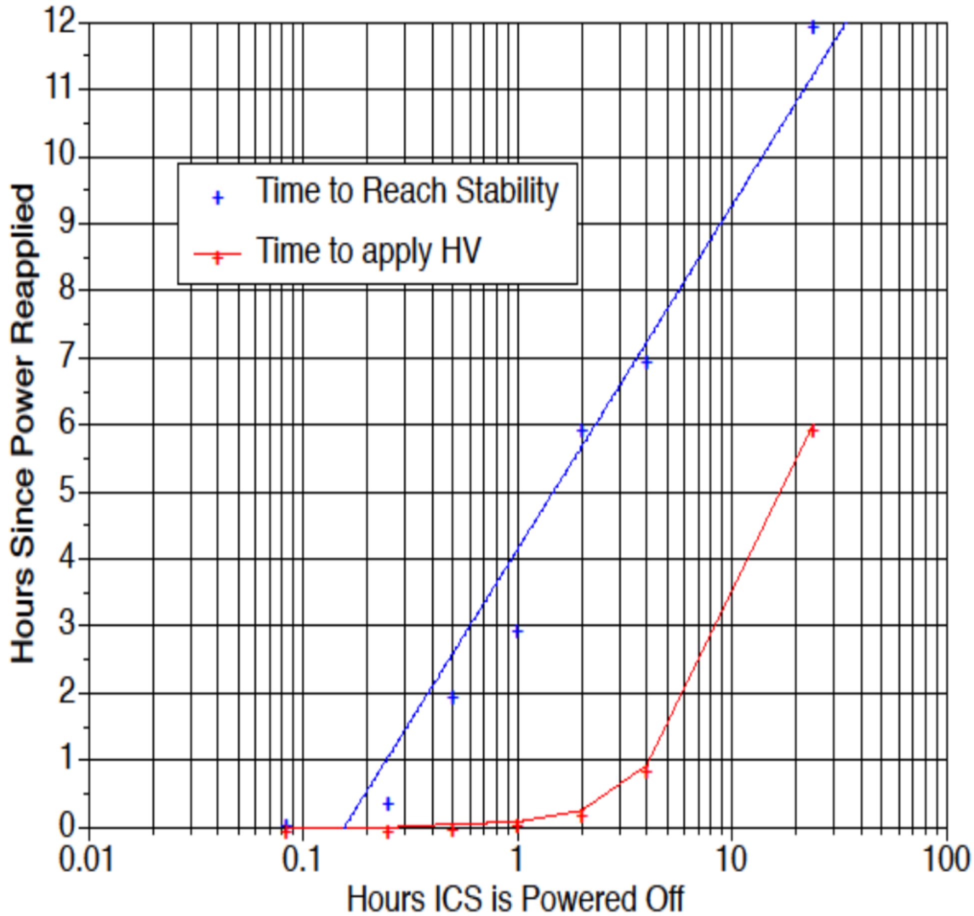

Fig. 6. Quick reference graph of how long it takes the Mod 1 ICS to be cold and stable as a function of how long its power was off.

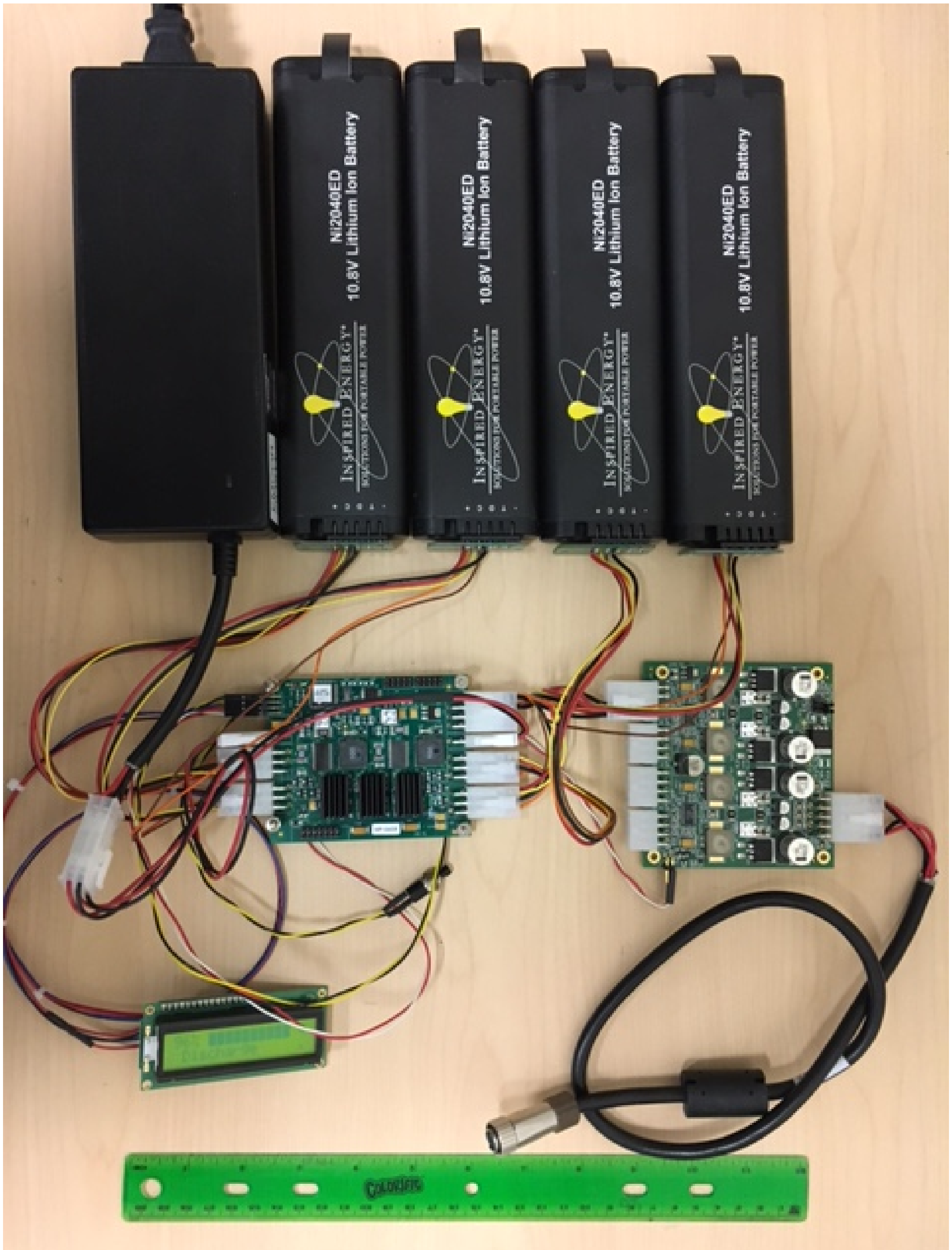

Fig. 7. Battery system capable of operating the Mod 1 ICS for up to 8 hours.
Top row: ICS power brick and four hot-swappable MC-15 type Li batteries
Second row: Li-battery charger/monitor board and 12V/24 V converter board
Third row: Status display and cable to the ICS. 12” ruler for reference.

Attachment 1. ORTEC's Statement of Work. Note they refer to Phase 1 and Phase 2; we refer to Mod 1 and Mod 2 to avoid confusion.

<u>ICS Conversion of LANL GEM140 PopTop Detector</u>
Statement of Work
02-09-15

This document serves as a Statement of Work for the process to convert an existing liquid nitrogen cooled PopTop GEM detector into a modified ICS (Integrated Cryocooled System) configuration. The modification will require shipment of the PopTop detector from LANL to the factory in Oak Ridge, TN for teardown, engineering, modification, manufacture and testing. Upon completion of this process, the detector will be returned to the purchaser (LLNL) for further evaluation and testing. Delivery to the end user (NA-42 group at Kirtland AFB in Albuquerque) will be fulfilled by the buyer.

There will be two phases involved in the ICS conversion project. The first phase of the project will apply to the first detector sent in for conversion. The second phase will be applicable to any future detectors sent in by the customer, and will involve a feedback stage from the customer as to other modifications they would like made on future units. Requested engineering modifications that are reviewed, substantiated, and approved after evaluation of the first unit will be implemented in future conversions upon receipt of purchase order from the customer. It is understood between the Supplier (ORTEC) and the customer that any future modifications requested/negotiated in Phase 2 will require re-evaluation and will incur any necessary NRE (Non-Renewable Engineering) costs to implement the changes. The phases of this project, specifications, and requirements are described below.

PHASE 1:

<u>Summary</u>

Convert the current detector from a liquid nitrogen cooled system to a mechanically cooled unit (ICS), eliminating the need for constant supply of LN2 for the operation of the system.

Customer requested modification to location of detector outputs/inputs and indicator LED’s, as well as conversion of detector to Smart type for monitoring of detector temperature. Customer also requested change of BNC connectors to DIM type Connector on housing.

Specifications for Conversion (Phase 1):

1. Maintain current detector performance specs for efficiency and resolution to within 10% of the measured performance of the GEM140 detector returned from LANL

2. Change of the current standard ICS model connections from BNC connectors to a standard DIM port for interfacing of the detector with the ICS.

3. Change current location of the detector interface connections, on/off switch, input power connector, and LED indicator lights to rear of the ICS. Reference “LANL ICS Assembly, REV B” concept drawing

4. Lead time for the conversion is 150 days (or less)

5. In the event that the detector requires reprocessing to restore acceptable performance, additional charges may apply. This will be reviewed with LANL (John Bounds) on an as needed basis.

PHASE 2:

Summary

After Customer has received initial unit from Phase 1, the customer will begin their own testing and evaluation of unit. Customer will work with Sales Engineer to provide feedback about the unit performance and their evaluation of the unit’s acceptability for use in their current application in the current form factor.

Unit will also be fitted with collimator by the customer, and any suggested engineering changes associated with this will be communicated to Supplier

(ORTEC) in formal request. Any other desired changes to the unit design or operation for future implementation will also be submitted as a formal request, through the Sales Engineer. These requests will be evaluated for feasibility, acceptability, and cost by the supplier.

No engineering changes will be made without complete approval and sign off from the Supplier, which will be followed by submission of a quote for the desired changes to the customer.   Quoted engineering changes will not be implemented until the supplier has received a purchase order from the customer for the determined NRE costs as designated in the provided quote from the supplier.

Specifications for Conversion (Phase 2):

1. Engineering and design for attachment of a handle and carrying cradle for ICS unit similar to what was being used on the previous LN2 cooled system

2. Engineering and design of a collimator mount on the carrying cradle

3. Other user specified modifications intended to maintain/improve functionality of instrument as it exists in the current configuration

4. Communication of desired changes/modifications will be submitted to the Sales Engineer, who will facilitate communication between the Customer and Supplier about all changes and requests.

5. All requests for changes will need final review and approval from Supplier, and upon approval the quoted costs for requested changes will be submitted to the Customer in a formal quote. The Supplier's quote will include an itemized line item cost substantiating the specific work being performed for submittal and approval from procurement.

6. The Supplier must have a PO (purchase order) from the customer in order to start any of the quoted work on any customer supplied units.